Method and device for control of the operation of a nitrogen oxides trap for an internal combustion engine running on lean mixture.
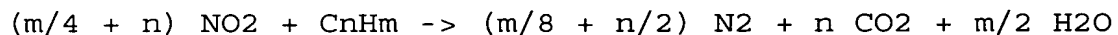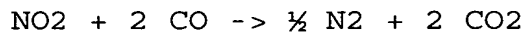
The present invention relates to a method and a device for control of the operation of a nitrogen oxides trap for an internal combustion engine running on lean mixture.

More particularly, it is intended for diesel engines, or in general for engines whose operation takes place under conditions of emission of exhaust gas with relatively low richness.

The use of catalysts of the nitrogen oxides trap type, also commonly known as "Nox Trap", is already known in diesel engines. It corresponds to the desire to avoid discharge of nitrogen oxides in the exhaust gases, since the emission of nitrogen oxides at the engine outlet is increasing with the current attempts to run the engines on lean mixture, that is under conditions of excess oxygen relative to the fuel and therefore excess air. In other words, in this type of operation with lean mixture, the richness at the intake is lower than 1, the value corresponding to a stoichiometric mixture.

During operation of the engine, a nitrogen oxides trap continuously captures the nitrogen oxides contained in the exhaust gases produced by the said engine. It is therefore necessary to regenerate the nitrogen oxides trap periodically in order to unburden it, which is achieved by an operation known as purging, during which

the nitrogen oxides content is reduced. It is known to perform this purging periodically, temporarily commanding the richness of the engine to be increased, in such a way that the richness of the exhaust gases upstream from the nitrogen oxides trap is greater than 1 and that the oxygen concentration is low, that is, such that the engine generates reducing agents such as HC, CO and H_2, capable of reducing the nitrogen oxides stored on the substrate of the trap, by means of the following reactions:

$$NO2 + 2\ H2 \rightarrow \tfrac{1}{2}\ N2 + 2\ H2O$$

$$NO2 + 2\ CO \rightarrow \tfrac{1}{2}\ N2 + 2\ CO2$$

$$(m/4 + n)\ NO2 + CnHm \rightarrow (m/8 + n/2)\ N2 + n\ CO2 + m/2\ H2O$$

Termination of the purging can be commanded, for example, at the end of a predetermined time after the engine was changed over to running on rich mixture. However, that does not make any allowance for the real burden of the nitrogen oxides trap, and there is the risk that either purging will be incomplete or that the phase of running on rich mixture will be impractically long.

The object of the present invention is to overcome this problem and in particular to provide a method and means with which it is possible, in optimal manner, to command a stop to purging of a catalyst of the nitrogen oxides trap type disposed in the exhaust line of an internal combustion engine that normally runs on lean mixture.

With these objectives in mind, the object of the invention is a method for control of the operation of a nitrogen oxides trap for an internal combustion engine running on lean mixture, wherein purging of the said nitrogen oxides trap is commanded periodically.

According to the invention, this method is characterized in that a first oxygen sensor is disposed in the exhaust pipe downstream from the nitrogen oxides trap, and the evolution of a meaningful signal representative of the signal delivered by this sensor is observed, a substantial increase of this meaningful signal from a first plateau of substantially constant level, reached following a variation subsequent to a changeover of the engine from running on lean mixture to running on rich mixture, being used as the indicator to command the end of purging.

In the method according to the invention, the command to end purging of the nitrogen oxides trap is therefore achieved in response to a notable evolution of the meaningful signal representative of the condition of the oxygen sensor disposed downstream from the trap, this evolution comprising a marked increase of the signal beyond a first plateau reached practically as soon as the beginning of purging and at which the signal had previously substantially stabilized. The inventors in fact observed that, under substantially constant conditions upstream from the nitrogen oxides trap during purging, the signal delivered by the oxygen sensor disposed downstream from the nitrogen oxides trap still underwent a meaningful evolution at the moment when the

reduction of all stored nitrogen oxides was sufficiently
complete.

One difficulty encountered was actually that, in the
case of engines running on lean mixture, such as diesel
engines, the signal of an oxygen sensor disposed
downstream from the nitrogen oxides trap shoots up almost
immediately, as soon as purging is initiated, and that
therefore this premature upward shoot obviously could not
be used to indicate the end of reduction of the nitrogen
oxides stored in the nitrogen oxides trap.

It is recalled here that lambda sensors normally
deliver a signal that is practically binary as a function
of whether or not oxygen is being detected. Proportional
sensors are certainly more suitable for measuring a range
of concentrations or progressive variations, but the
signal that they are capable of delivering nevertheless
varies abruptly if the evolution of the oxygen content is
strong and fast.

For engines running on lean mixture, the initiation
of purging, which takes place by changeover to a
substantially richer mode of operation in order to
provide reducing elements capable of reacting with the
stored nitrogen oxides, leads to a large excess of HC in
the gases passing through the nitrogen oxides trap and
arriving immediately at the downstream sensor, which
itself reacts almost immediately by reaching saturation.

It was known beforehand, in the case of a gasoline
engine running on lean mixture, that the upward shoot of
the signal of the sensor indicated the disappearance of

oxygen at the outlet of the nitrogen oxides trap, which
therefore could be interpreted as the end of purging,
that is, the arrival again of a reducing mixture at the
sensor, whereas previously, during purging, the reducing
agents originating from the engine were being consumed by
the reduction reactions used for purging. In fact, in
this case, the proportion of CO to HC in the exhaust
gases is relatively high, but, since the reducing power
of CO is much stronger than that of HC, a kind of
equilibrium is established between the aforesaid
reduction reactions, leading to a substantially
equivalent participation of all reducing agents delivered
by the engine in purging of the nitrogen oxides trap. As
a result, the gaseous mixture exiting the nitrogen oxides
trap then remains without effect on the sensor while
these reactions are occurring, and it is only at the end
of the reduction reactions that the reducing agents are
then present in excess at the outlet of the nitrogen
oxides trap, causing the sensor signal to shoot up, since
it is then truly representative of the end of purging.

     In contrast to the foregoing, it became apparent to
the inventors that, in the case of the engines considered
by the present invention, operating with a richness on
the order of 1 to 1.1, the upward shoot of the signal
takes place almost as soon as purging begins following
the relatively massive arrival of HC at the sensor
disposed downstream from the nitrogen oxides trap. An
explanation of this phenomenon, which does not occur in
the case of operation with greater richness, such as 1.2
to 1.4, appears to lie in the fact that the HC/CO ratio
is higher in the exhaust gases in the case of operation
with lower richness. In fact, the evolution of CO content

as a function of richness is exponential, while it is
linear for HC. Now, since the reducing power of H_2 and of
CO is greater than that of HC, the purging reactions will
therefore take place preferentially with these H_2 and CO
reducing agents but, because of the relative excess of
HC, the equilibrium of reactions mentioned in the
foregoing no longer is established, thus leading to the
presence of unreacted HC at the outlet of the nitrogen
oxides trap practically as soon as purging begins. The
variation of the signal delivered by the sensor therefore
no longer is indicative of the total reduction of the
nitrogen oxides contained in the nitrogen oxides trap,
but to the contrary is evident as soon as purging begins.

The inventors therefore searched for another means
of detecting this end of purging. They discovered that,
surprisingly, since in particular the lambda sensors are
considered to deliver a quasi-binary signal, this signal
delivered by an oxygen sensor underwent a new variation
starting from a substantially constant plateau at which
the arrival of the HC had caused the signal to shoot up
as soon as purging began.

An analysis of this phenomenon led to the
observation that, after the signal arrived in this way at
the level of the first plateau and was maintained there
during purging as long as the aforesaid reduction
reactions did not treat the majority of the nitrogen
oxides stored on the catalyst substrate of the nitrogen
oxides trap, this signal shifted to a second plateau of
higher level, substantially at the moment of the end of
the said reduction reactions, and then remained at this

level as long as the engine continued to run on rich
mixture. The inventors then imagined taking advantage of
this evolution of the shift of the signal from the first
to the second plateau as an indicator of the end of
purging and thus for commanding automatically the return
to running the engine on normal mixture, that is, on lean
mixture.

One explanation of this phenomenon is that, during
the purging phase, the quantity of hydrogen downstream
from the nitrogen oxides trap is close to zero, because
the hydrogen upstream is consumed almost completely by
the catalytic reactions, the reducing power of H_2 being
predominant, as already indicated hereinabove. When the
reduction reactions are terminated by virtue of the small
residual quantity of nitrogen oxides stored in the
nitrogen oxides trap, the HC, CO and H_2 reducing agents
will be found in increasing concentration downstream from
the nitrogen oxides trap and simultaneously will favor
the formation of H_2 within the nitrogen oxides trap via
various mechanisms, including in particular:

$$H_2O + CO \rightarrow H_2 + CO_2$$
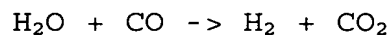
This formation of H_2 was measured by gas-phase
chromatography and continuous mass spectrometry.

This modification of the concentration of reducing
agents downstream from the nitrogen oxides trap
influences the signal of oxygen sensors of all-or-nothing
type, such as the lambda sensors or the sensors of
proportional type, such as the sensors known under the

name of UEGO® sensor, which then present a signal in the
form of the said second plateau situated at a level
higher than the first plateau. The oxygen sensors of the
lambda type and the oxygen sensors of the proportional
type are particularly sensitive to hydrogen present in
the exhaust gases, and they exhibit a large variation of
their signal when the H2 concentration in the exhaust
gases changes and therefore during the shift from the
first to the second plateau.

This particular feature therefore made it possible
to take advantage of the variation of the signal from its
first plateau to detect the end of purging and
consequently to command the engine to return to running
on poor mixture, if necessary with a certain time delay
after detection of the variation proper.

According to a particular arrangement of the
invention, there is additionally used a second oxygen
sensor disposed upstream from the nitrogen oxides trap,
in order to deliver a reference signal relative to which
the evolution of the signal delivered by the first sensor
is compared in order to deliver the said meaningful
signal. The use of this reference signal, which can be
influenced by variations of the operating conditions of
the engine independent of those programmed for the
purging operation proper, therefore makes it possible, by
comparison, to reliably detect the variation that is
indicative of the end of the reduction reactions in the
nitrogen oxides trap.

In addition, with oxygen sensors of the same type

upstream and downstream from the nitrogen oxides trap,
for example two lambda sensors or two proportional
sensors, the sensitive element of which is temperature-
controlled or else the signal of which is corrected as a
function of the temperature of the sensitive element, the
higher H_2 concentration in the gases downstream than in
the gases upstream from the nitrogen oxides trap is
manifested by a higher signal for the sensor situated
downstream than for the sensor situated upstream when the
reduction of the stored nitrogen oxides is sufficiently
advanced.

As a function of the H_2 concentration upstream, and
in the case in which two lambda sensors are used, the
signal of the upstream lambda sensor can be at the same
level as the signal of the downstream lambda sensor at
the second plateau.

Traditionally, the oxygen sensor or sensors will be
chosen from among the sensors of the following type:
sensor of lambda type, proportional oxygen sensor,
nitrogen oxides detector, in which the capability of
measuring the oxygen concentration is used.

In the case of use of a sensor upstream and of a
sensor downstream from the nitrogen oxides trap, it will
also be possible for the two sensors to be of different
types, and particular, it will then be possible to use,
for the purposes of the invention, sensors that may
already be installed in the exhaust line to perform other
functions. In particular, it will be possible to use the
different combinations listed in the following table.

Upstream sensor	Downstream sensor
Proportional sensor	Lambda sensor
Proportional sensor	O2 function of the Nox detector
Lambda sensor	Proportional sensor
Lambda sensor	O2 function of the Nox detector
O2 function of the Nox detector	Lambda sensor
O2 function of the Nox detector	Proportional sensor

where "O2 function of the Nox detector" denotes the
use of the oxygen-concentration measuring function of a
nitrogen oxides detector, as indicated in the foregoing.

When two oxygen sensors of different nature are
used, it is necessary either to introduce a transfer
function between the sensor signals (taking into account
any differences in response times) or to use cells
equivalent to that of the lambda sensor.

According to a first embodiment, the increase of the
meaningful signal is detected by applying filtering of
the first derivative of the meaningful signal and by
comparing the filtered first derivative with a
predetermined threshold.

According to a second embodiment, the increase of
the meaningful signal is detected by applying filtering
of the second derivative of the meaningful signal and
observing the passage of the filtered second derivative
through zero in decreasing threshold.

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According to a third embodiment, the increase of the meaningful signal is detected by taking the difference between the instantaneous value of the meaningful signal and a sliding mean of the said signal, and by comparing this difference with a threshold.

According to a fourth embodiment, the increase of the meaningful signal, for a lambda sensor, is detected by comparing the voltage value delivered by the sensor with a predetermined threshold.

A practical example of the invention will now be described for a diesel engine.

Reference will be made to the attached drawings, wherein:

-       Fig. 1 is a schematic and partial representation of the gas circuit of the said engine,

-       Fig. 2 is a graph that shows the curves representative of the signal of different sensors disposed upstream and downstream from the nitrogen oxides trap, and that illustrates the variation of the signal used as indicator of the end of purging.

On Fig. 1 there are schematically represented the elements of the engine through which the gases pass, and there are seen therein, successively in the direction of flow of the gases:

- inlet 11 for air arriving from the air filter,
- suction part 12 of a turbocompressor,
- intake manifold 13,
- the upper part of cylinder 14, equipped with an

injector 15,

        - exhaust tubes 16 and the exhaust part 17 of the
turbocompressor,

        - nitrogen oxides trap 18,

        - the exhaust line, equipped with a particle filter
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        A first oxygen sensor 21 is mounted downstream from
the nitrogen oxides trap, and a second oxygen sensor 22
is mounted upstream from the nitrogen oxides trap, the
two sensors being connected to a calculating unit 23,
which itself is connected to an engine-control unit 24.

        Sensors 21 and 22 are, for example, proportional or
lambda sensors.

        The graph of Fig. 2 shows the results of test
measurements performed with different types of sensors as
a function of the time from initiation of purging. On the
ordinate, the left scale represents the value of the
signal delivered by a sensor, and the right scale
represents the quantity of CO downstream from the
nitrogen oxides trap (for trace 6).

        Line 3 represents the signal delivered by a sensor
of lambda type disposed downstream from the nitrogen
oxides trap. On the line there is clearly seen the upward
shoot 31 of the sensor as soon as purging begins, and the
first plateau 32 which remains substantially stable
during purging, then the marked variation 34 of the
signal, representative of the arrival of H_2 at the sensor
and is therefore indicative of the end of purging, before
the signal restabilizes at a second plateau 33.

Line 4 represents the signal delivered by a sensor
of proportional type disposed downstream from the
nitrogen oxides trap. On the line there is clearly seen
the upward shoot 41 of the sensor as soon as purging
begins, and the first plateau 42 which remains
substantially stable during purging, then the marked
variation 44 of the signal, representative of the arrival
of H_2 at the sensor and is therefore indicative of the end
of purging, before the signal restabilizes at a second
plateau 43.

In comparison, line 5 represents the signal
delivered by a sensor of proportional type disposed
upstream from the nitrogen oxides trap. It is clearly
seen that this signal also undergoes an abrupt rise 51 at
the moment of initiation of purging, due to the influx of
reducing agents in the exhaust gases. In contrast, the
signal then remains constant on a plateau 52, as long as
the engine is maintained under constant conditions of
running on rich mixture. In the event of any perturbation
whatsoever of these conditions during purging, that
perturbation will correspondingly affect both the
upstream sensor and the sensor situated downstream from
the nitrogen oxides trap, and it will be possible to use
this signal delivered by the upstream sensor as a
reference for evaluating, by comparison, the variations
of the signal of the downstream sensor, truly indicative
of the end of purging.

It will also be noted that the level of plateau 42
is situated below plateau 52, the difference
corresponding to the fraction of the reducing agents used
to reduce the nitrogen oxides stored in the filter. In
contrast, when purging is terminated, the signal of the

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downstream sensor shifts above that of the upstream
sensor, clearly illustrating the arrival at the sensor of
the hydrogen formed in the nitrogen oxides trap by the
aforesaid reaction mechanism.

On this graph there was also represented a line 6
representing the evolution of the CO content downstream
from the nitrogen oxides trap, measured in experimental
manner, and the evolution of which, marked by the strong
increase 61 at the moment when the sensor signals shift
from the first to the second plateau, clearly
corroborates the end of consumption of the said CO for
reducing the nitrogen oxides stored in the nitrogen
oxides trap, and therefore the advanced disappearance
thereof.

As an example of how the signal obtained from the
sensors is processed, there was also represented in the
graph the line 7, which represents the filtered first
derivative of the signal, and illustrates the possibility
of detecting the end of purging by comparing this signal
with a predetermined threshold, crossed by the said
derivative during its abrupt increase 71, corresponding
to the increase of the slope of the signal obtained from
the sensor.

Similarly, there was also represented the line 8,
which represents the second derivative, whose passage
through zero in decreasing threshold 81 can also be used
as information indicative of the end of purging.

The invention is not limited to the examples
described hereinabove. It is intended more particularly
for diesel engines, but it could also be applied in

general to all engines that normally run on lean mixture.